REINFORCED CONCRETE
STREET-CROSSING FOR TRACK ELEVATION

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

1912

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THE COMPLETE DESIGN
# of a
REINFORCED CONCRETE STREET-CROSSING
for
TRACK ELEVATION.

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A THESIS

Presented by Fred C. Dierking

to the

PRESIDENT and FACULTY

of the

ARMOUR INSTITUTE OF TECHNOLOGY

for the degree of

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

*

Having completed the prescribed course

Of study in Civil Engineering.

1912

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THE COMPLETE DESIGN
# of a
REINFORCED CONCRETE STREET-CROSSING
for
TRACK ELEVATION.

The location chosen as the site forthe structure designed in this thesis was the intersection of the C.M.&St.P.Ry.(Bloomingdale Road) and N.Western Avenue in the city of Chicago,which is at present a grade crossing. The general layout of existing conditions as obtained from a survey and from records in the office of the Division Engineer is shown on Plate I. It will be observed that the angle of intersection is practically a right angle(89 degrees,36 minutes). At present the space along the north side of the tracks is used for street traffic. In order to allow the continuance of this traffic after elevation has taken

place, the general design as shown in Plate II. will be adopted. The tracks will be shifted as indicated, and also the north curb of the street so that a space of 15 feet remains between it and the north face of the retaining wall. Plate II is shown merely to give an idea of the proposed work, and the dimensions have been modified slightly in the final design.

The actual work of design divides itself naturally into three parts, as follows:

I. Design of Slabs.
II. '' " Piers.
III. " " Abutments.

The discussion will be divided similarly, and we will therefore take up the

DESIGN OF SLABS.

The computations for slab-design are shown in plates III to IV-a inclusive and the detailed drawings on Plate IX. The general considerations involved are as follows.

The live load consists of Cooper's E-50 loading, and on account of the presence of 12 to 27 inches of ballast below the base of rail the stresses due to impact were taken as 50% of those due to the live load. On account of the large ratio of the thickness of the slabs to their length, and also the generous allowances of ballast and slab reinforcement, the live load was assumed as spread over the entire width of the slabs. The longitudinal reinforcing consists of square corrugated bars(1"and 3/4") as shown. These bars are placed with the straight and the bent ends alternating. The shear reinforcement consists of 1/2" babs, bent and spaced as shown. The lifting-stirrups consist of round round U-bars imbedded inthe slabs in the gravity axis. The calculation for the location of these stirrups is shown on Plate V. To provide for drainage the long slabs have gutters sloping toward the curbs,

while the sidewalk slabs slope uniformly to the abutment. The joints between the slabs ,and between the slabs and the abutments are filled with a 1:2 mortar and waterproofed.

DESIGN OF PIERS.

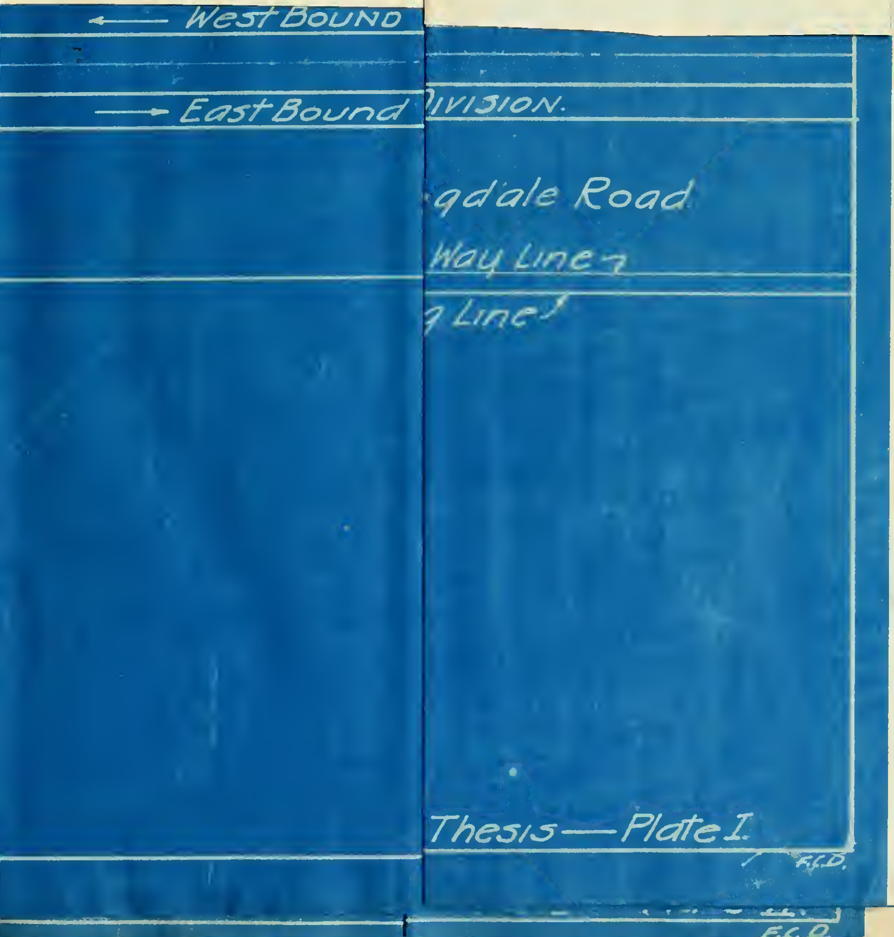
The design of the piers is shown on Plates VI toVII-b and the detailed drawings on Plate X. In designing,the slab reactions due to live and dead loads were considered as a uniform load on the cap,and the cap itself figured as a continuous beam,except between the columns where it was figured as a simple beam of shorter span. Stirrups and bent bars give the necessary web reinforcement to the cap. The center pier is somewhat heavier than the curb pier,and in it the column pedestals are replaced by a continuous base or wheelguard running the entire length of the footing. The footing was designed as a beam and 1"square bars were provided for

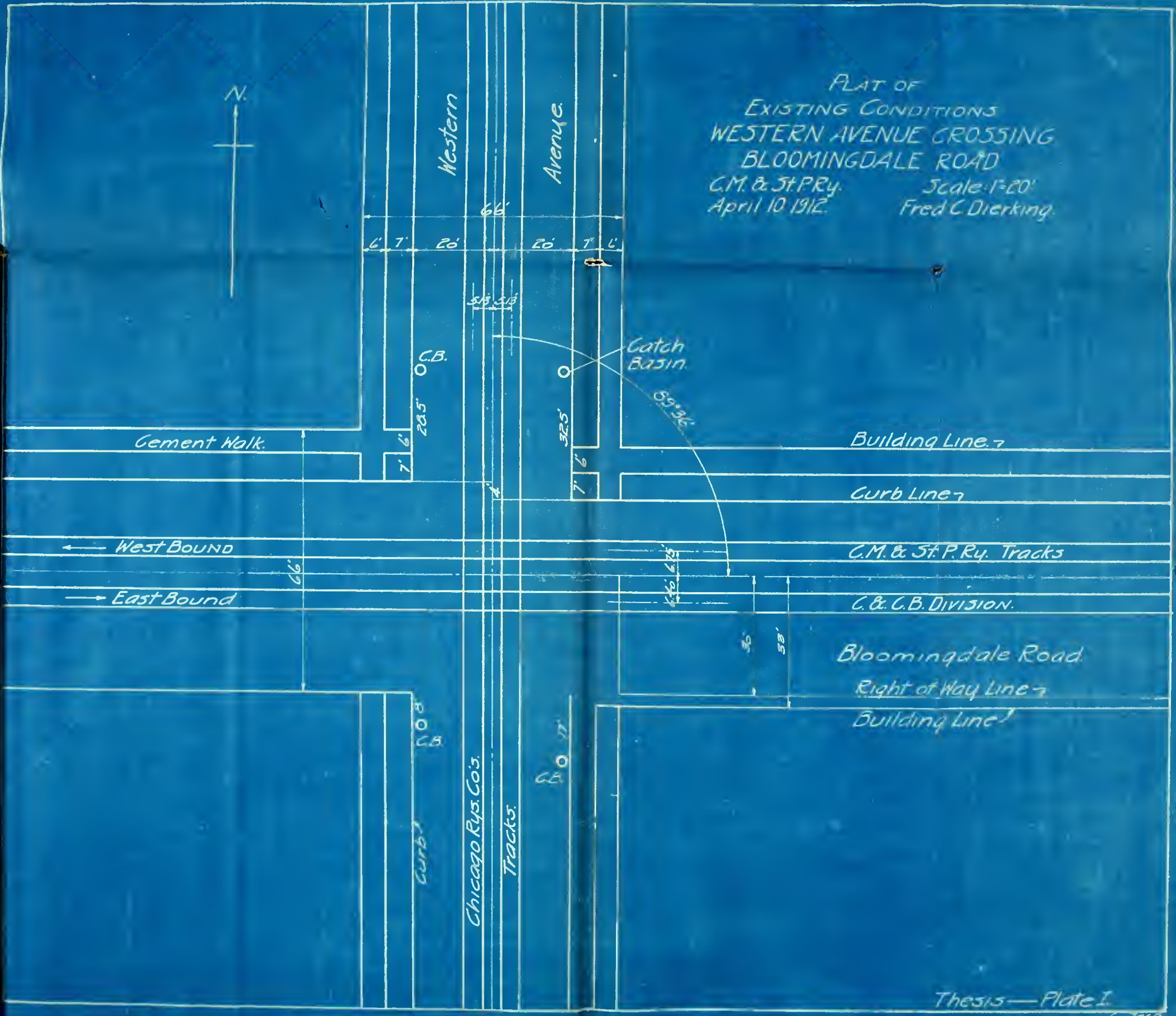
tensile reinforcement. The web reinforcement consists of 3/4" bars bent in the shape of a W. Transverse bars were also placed in the footing to provide for tension in the cantilever section of the base. The areas of the footings are such that the bearing pressures are the same for all piers,to avoid uneven settlement.

DESIGN OF ABUTMENTS.

The abutments are of the massive type,of gravity section above the footing and resting on the earth without piles. Their design is shown on PlatesVIII to VIII-b and the detailed drawings on Plate XI. The footings were designed so as to keep the bearing pressure below 4000#/square foot. The following forces were taken into consideration as acting on the abutment: (1)Earth pressure, figured according to Rankine's METHOD, with a surcharge of 10,000 #/foot of track spread over a width of 13 feet. (2)Reaction from the sidewalk slab. (3)Weight of the abutment. (4)Horizontal earth pressure on the footing.

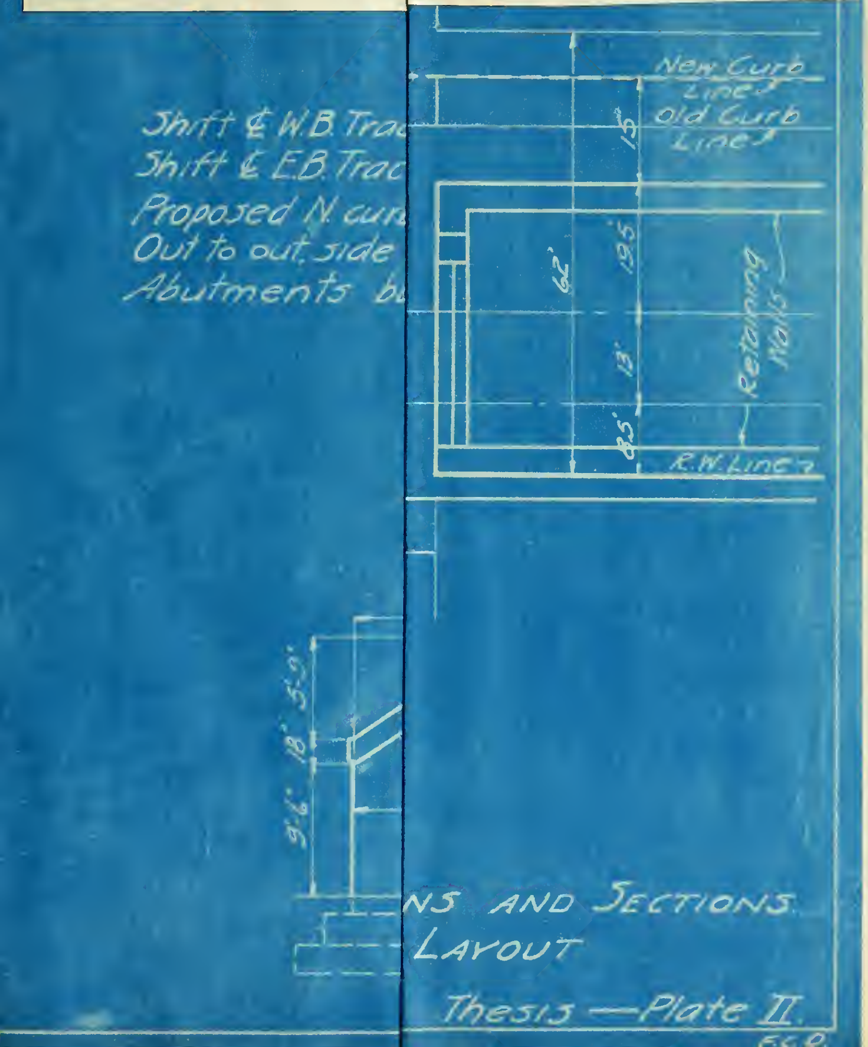
These forces were resolved into two forces one horizontal and one vertical,and the resultant of these last two forces was then found and the bearing pressure calculated. Transverse bars were placed in the footing to provide for tension in the cantilever. The slab-seat is so designed that natural drainage over it is possible.


← West Bound
→ East Bound
IVISION.
gdale Road
Way Line
g Line
Thesis — Plate I.
F.C.D.



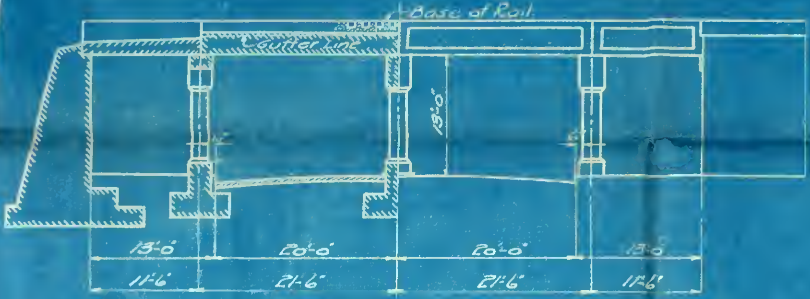
PLAT OF
EXISTING CONDITIONS
WESTERN AVENUE CROSSING
BLOOMINGDALE ROAD
C.M. & St. P. Ry.
Scale 1"=20'
April 10 1912.
Fred C. Dierking.

Thesis — Plate I.

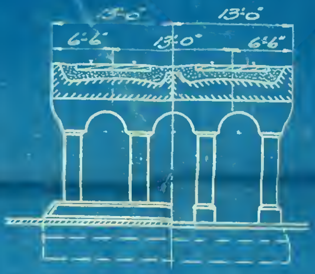


NS AND SECTIONS
LAYOUT

Thesis — Plate II.



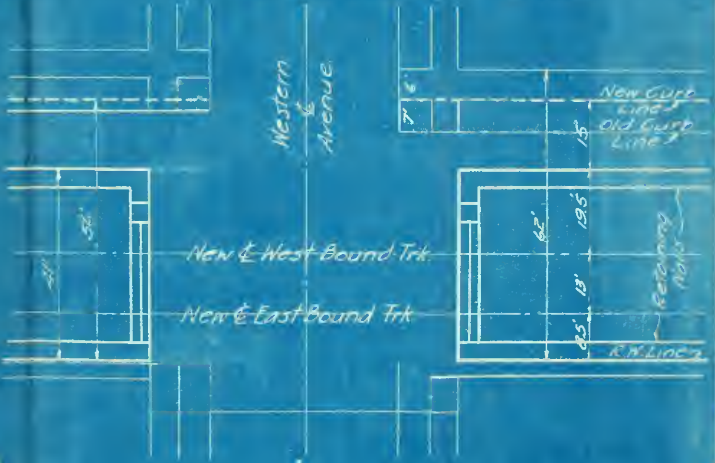
Half Section   Half Elevation



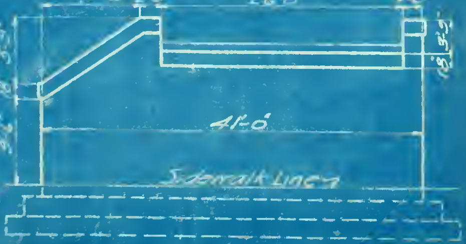
Half Sections

at ℄ of Street   at Curb

Shift ℄ W.B. Track 15.25' to the South
Shift ℄ E.B. Track 15.1' to the South.
Proposed N. curb 5.6' N. of R.W. Line.
Out to out side Ret'g Walls: 41'-0"
Abutments built to Build'g Lines.



Abutment – Elevation.



GENERAL ELEVATIONS AND SECTIONS
WITH PROPOSED LAYOUT

Scale: 1"=10'-0"

Thesis — Plate II.

F.C.O.

Plate III

DESIGN OF SLABS "A."

Length overall = 21'-6"

Width " = 13'-0"

Average Thickness = 2'-9"

Weight per ft. slab: $13 \cdot 2.75 \cdot 150$ = 5360#

" " " ballast: $13 \cdot 120$ = 1560#

" " " rails etc = 75#

" " " ties = 105#

Total: 7100#

L.L.B.M. (Coopers E-50) 589000 ft#

Impact 50 % 284500 "

D.L.B.M. $7100 \cdot 1/8 \cdot 20^2$ 355000

Total M = 1228600 " = 14720000 in#

$f_s = 13500\#/\square''$ $f_c = 750\#/\square''$ $n = 12$ $p = .0105$

$R_c = R_s = 122$ $d = 28''$

$M_c = M_s = 122 \times 13 \times 12 \times 28^2 = 14900000$ in#

Area steel = $.0105 \times 28 \times 13 \times 12 = 46\,\square''$

Using 1□" bars, space 40 @ 3¼" and 6 @ 3½".

WEB: L.L. End Shear = 130000#

Impact 50% = 65000#

D.L. End Shear = 75000#

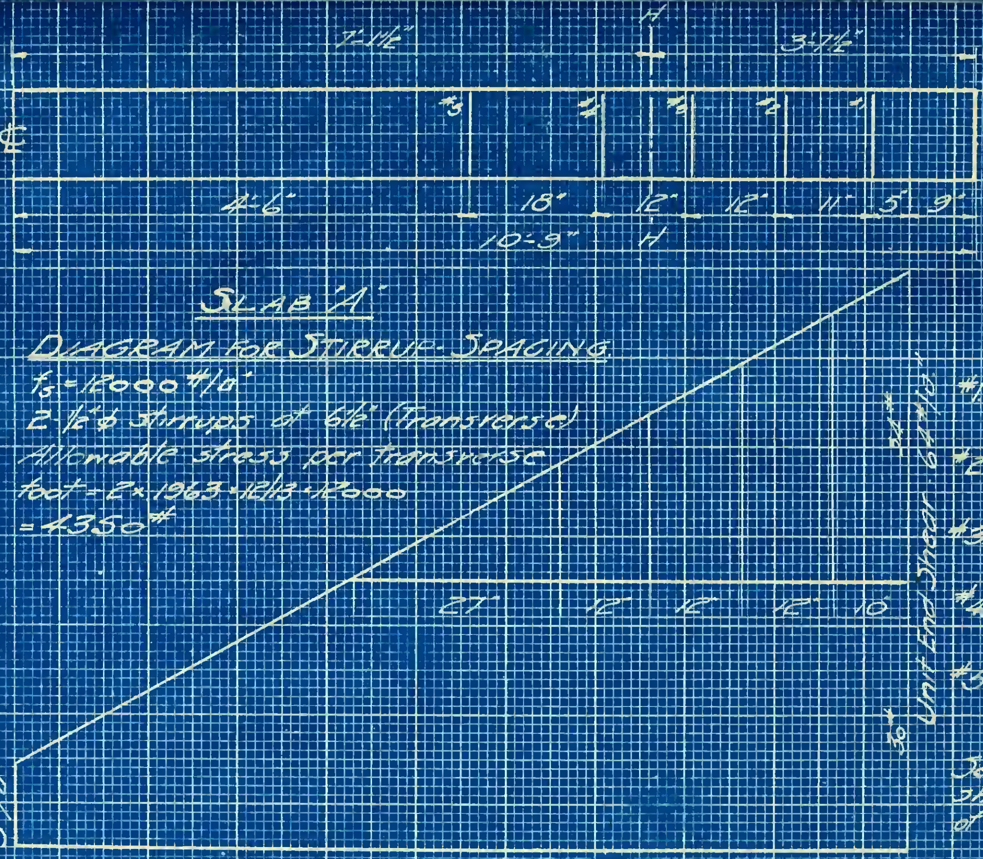
Total = 270000#

Unit Shear = $270000 / 13 \cdot 12 \cdot 28 = 64\#/\square''$

30#/□" taken by concrete, 34#/□" by web steel.

Unit shear at center due to L.L. = 9#/sq.in.

Plate III-a.



SLAB 'A'

DIAGRAM FOR STIRRUP-SPACING

f_s = 12000#/□"

2 ½"φ stirrups at 6½" (Transverse)

Allowable stress per transverse foot = 2×.1963×12/13×12000 = 4350#

STRESSES

P = V·b·s

#1. P = 10·12·31.5 = 3780#

#2. P = 12·12·26 = 3740#

#3. P = 12·12·21 = = 3040#

#4 P = 12·12·15 = 2160#

#5. P = 12·27·7 = 2270#

Section H-H shows position of handling rods

Thesis - A.C.D.

Plate IV

DESIGN OF SLABS "B"

Length overall = 12'-6" Width = 13'-0"

Effective length = 11'-0"

Average thickness = 1'-10"

Weight per ft. slab: 13 × 1.85 × 150 = 3600#

" " " ballast 13 × 2 × 120 = 3120#

" " " track: 75#

" " " ties: 105#

Total: 6900#

L.L. B.M (Coopers E-50): 164000 ft#

Impact 50 %: 82000 "

D.L. B.M 6900 × 121 × 1/8: 105000

Total = 351000 = 4,201,000 in#

$f_s = 13500$ #/□" $d = 15$"

$f_c = 750$ #/□" $n = 12$ $p = .0105$ $R_c = R_s = 122$

$M_c = M_s = 122 \times 13 \times 12 \times 225 = 4{,}280{,}000$ in#

Area steel = .0105 × 13 × 12 × 15 = 25 □"

Use 44 - 3/4 □ bars, spacing 40 @ 3¼ and 4 at 5

Web: L.L. End Shear = 82000#

Impact 50% = 41000#

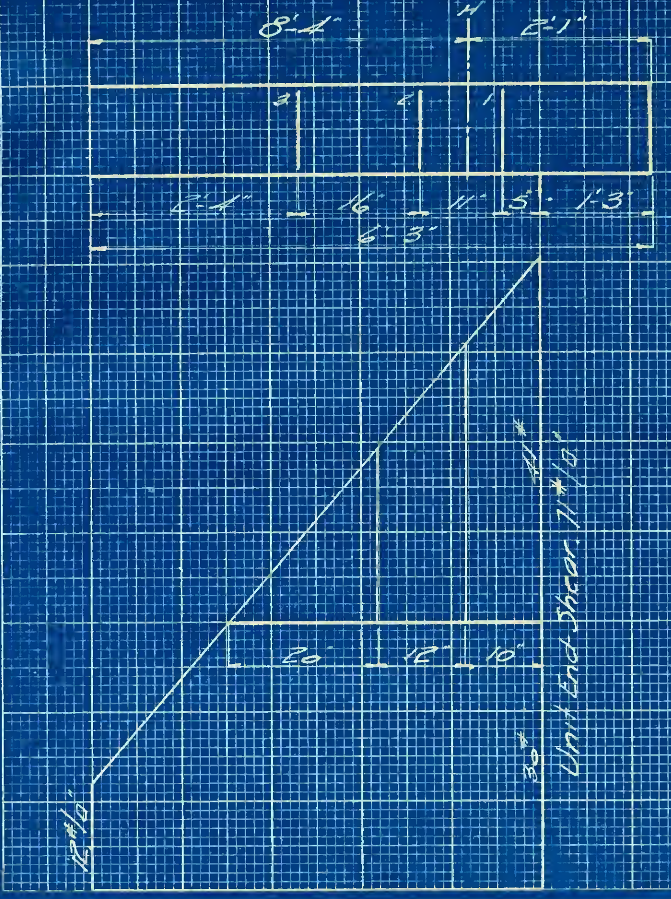
D.L. End Shear = 43000#

Total = 166000#

Unit End Shear = 166000 / 13 × 12 × 15 = 71 #/□"

30 #/□" taken by concrete, 41# by steel.

Plate IV-a.



SLAB "B"

DIAGRAM FOR STIRRUP-SPACING.

$f_s = 12000\#/\square''$

1/2" φ stirrups. 2 per ft transverse

Allowable stress per transverse foot = 2 × .1963 × 12/13 × 12000 = 4350#

STRESSES. P = vbs

$P_1 = 10 \cdot 12 \cdot 36 = 4320\#$

$P_2 = 12 \cdot 12 \cdot 25 = 3600\#$

$P_3 = 20 \cdot 12 \cdot 9 = 2160\#$

Section H indicates position of handling bars.

Thesis F.C.O.

FREEMAN AND SNOW

Plate V

POSITION OF LIFTING STIRRUPS.

1 For equal bending moment : $Wl_1/8 = Wl_2/2$

2 Also $l_1 + 2l_2 = l$

From ∴ $l_1 = 4l_2$ ∴ $2l_2 + 4l_2 = l$ ∴ $l_2 = l/6$

For Slab "A" $l_1 = 2l/3$

$l_1 = 14'\text{-}3''$ $l_2 = 3'\text{-}7\tfrac{1}{2}''$

For Slab "B"

$l_1 = 8'\text{-}4''$ $l_2 = 2'\text{-}1''$

SIZES OF LIFTING STIRRUPS

Slab A: $d = \dfrac{3600 \times 21.5}{16000 \times 4} = 1.8\ \square''$

∴ use 1½" ϕ steel

Slab B: $a = \dfrac{3600 \times 12.5}{16000 \times 4} = .70\ \square''$

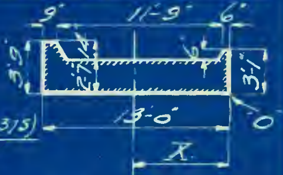
∴ use 1" ϕ steel

TRANSVERSE POSITION - LIFTING STIRRUPS.

To find axis of symetry, take moments about "O".

$$\underline{X} = \frac{(13 \times 2.38 \times 6.5) + (1.16 \times 1.125 \times 12.44) + (.5 \times .75 \times .375)}{30.9 + 1.31 + 3.75}$$

$$= 217.44/32.585 = 6.68' = 6'\text{-}8\tfrac{1}{4}''$$ Slab "A"

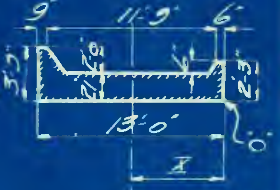


Slab B:-

$$\underline{X} = \frac{(22.8 \times 6.5) + (2.5 \times 12.375) + (.375 \times .375)}{22.8 + 2.5 + .375}$$

$$= 179/25.675 = 6.97$$

$$= 6'\text{-}11\tfrac{3}{4}''$$



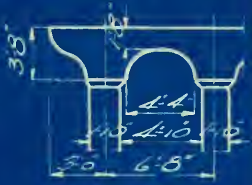
Slab "B"

Plate - VI.

DESIGN OF CENTER-PIER.

a Design of cap.

Width = 2'-0", Total length = 26'-0" = 3 spans @ 6'-8" + 2 @ 3'-0"



Loading:

LL Fl Bm Reaction E-50 = 153000# (1 track)

Impact 50 % = 76500#

DL Reaction (21.5 × 7100) = 152500#

Total for 13'-0" = 382000#

Load per linear foot = 29400#

Moments:

Over Supports: $\frac{1}{10} wl^2 = -1{,}560{,}000$ in#

Center of span: $\frac{1}{20} wl^2 = +830{,}000$ in#

Cantilevers: $wl/2$ = $-530{,}000$ in#

End-Shears:

Center panels: $wl/2A = 60$ #/□"

Cantilever span: $wl/A = 62$ #/□"

Design of Center Spans

Assume 4 □" of steel $d = 18"$

$f_c = M/\frac{1}{6}bd^2 = 830000 \times 6/24 \times 18^2 = 640$ #/□"

$f_s = M/\frac{7}{8}Ad = 830000 \times 8/7 \times 4 \times 18 = 13200$ #/□"

Over Supports:

$A = 4$ □" $f_s = 15000$# $f_c = 650$#

$d_s = M/\frac{7}{8}Af_s = 1560000/\frac{7}{8} \cdot 4 \times 15000 = 30"$ OK

$d_c = M/\frac{1}{6}f_c b^{1/2} = \sqrt{1560000/\frac{1}{6}\, 650 \cdot 24} = 25"$ OK

Cantilever Section:

$A = 4$ □" $d = 18"$

$f_c = 530000/\frac{1}{6} \cdot 18^2 \cdot 24 = 410$ #/□"

$f_s = 530000/\frac{7}{8} \cdot 4 \cdot 18 = 8400$ #/□"

(For web-steel see pl. VII-b).

Plate VI-a

b. Design of Columns.

Reaction per column : 191000#

Weight of cap " " : 6000#

Total load " " 197000#

$f_c = 500\#/\square''$ $n = 12$ $p = 2$

$P' = f_c \cdot A(1+(n-1)p)$

$\therefore A_c = 197000/500 \times 23 = 171 \square''$

Actual area = 18"×14" = 252 □"

$A_s = .02 \times 252 = 5.04 \square''$

c. Design of Footing.

Total reaction : 764000#

Weight of columns : 13000#

" " footing (est.) : 115000#

Total load 892000#

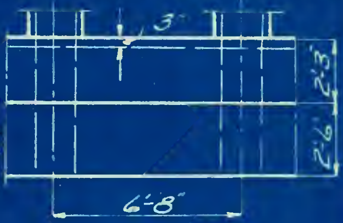
Bearing pressure = 892000/27×6 = 5500#

Footing Beam:

Pressure per lineal foot = 6×5500 = 33000#

$M = 33000 \times 6.6^2 \times 1.5 = 2{,}200{,}000\ \text{in}\#$

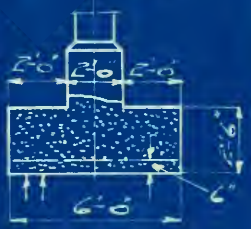
$$A_s = \frac{2200000 \times 8}{15000 \cdot 54 \cdot 7} = 3.1 \square''$$



Transverse Bars:

$$M = \frac{5500 \cdot 24}{2} = 66000\ \text{in}\#$$

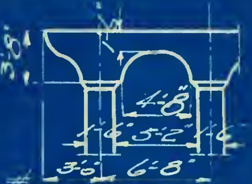
$$A_s = \frac{66000 \times 8}{15000 \cdot 24 \cdot 7} = .208 \square''$$



$$\text{Unit shear} = \frac{5500 \cdot 2}{24 \cdot 12} = 37\#/\square''$$

DESIGN OF CURB-PIER.

a Design of Cap.



Width 2'-0". Length 26'-2"

= 3 spans @ 6'-8" + 2 @ 3'-0"

Loading

L.L. Fl. Bm. Reaction	140000#
Impact 50%	70000#
D.L. Reaction	119000#
Total for 13'-0"	329000#

Load per linear foot = 25300#

Moments:

Over supports: $\frac{1}{10} wl^2 = -1{,}380{,}000$ in#

Panel-centres: $\frac{1}{8} wl^2 = +700{,}000$ in#

Cantilevers: $wl/2 = -455\,000$ in#

End-Shears:

Panels: $s = wl/2A = 51$ #/□"

Cantilevers: $s = wl/A = 48$ #/□"

Design of Center Spans:

Assume 4 □" of steel. $d = 16"$

$f_c = 700000 \times 6/24 \cdot 16^2 = 685$ #/□"

$f_s = 700\,000 \times 8/7 \times 4 \cdot 16 = 12500$ #/□"

Over supports:

$A_s = 4$ □" $f_s = 15000$ $f_c = 650$

$d_s = 1380\,000 \cdot 8/7 \cdot 4 \cdot 15000 = 26"$

$d_c = \sqrt{1380000 \cdot 6/650 \cdot 24} = 23"$

Cantilevers:

$A_s = 4$ □" $d = 16"$

$f_c = 455000 \times 6/24 \times 16^2 = 445$ #/□"

$f_s = 455000 \times 8/7 \times 16 \times 4 = 8100$ #/□"

b. Design of Columns:

Reaction per column: 164500#
Weight of cap 6000#
Total per column 170500#

$f_c = 500\#/\square''$ $n = 12$ $p = 2\%$

$A_c = P/f_c(1+(n-1)p)$

$= 170500/500 \times 23 = 150\ \square''$

Actual area $= 14'' \times 14'' = 196\ \square''$

$A_s = pA_c = .02 \times 196 = 3.92\ \square''$

c. Design of Footing:

Total reaction = 658000#
Columns 12000#
Footing (est) 85000#
Total load: 755000#

Bearing pressure $= 755000/27 \times 5$
$= 5600\#/\square'$

Footing Beam: (For sketches see preceding pages.)

Pressure per lineal foot $= 5 \times 5600$
$= 28000\#$

$M = 28000 \times 6.6^2 \times 1.5 = 1{,}830{,}000$ in.#

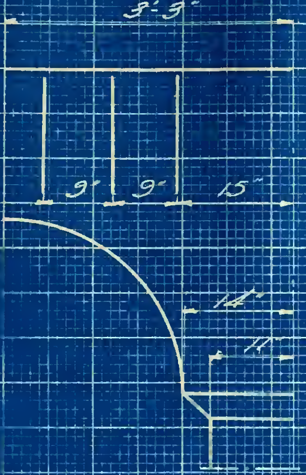
$$A_s = \frac{1830000 \times 8}{15000 \times 54 \times 7} = 2.6\ \square''$$

Transverse Bars:

$$M = \frac{5600 \times 18}{2} = 50500 \text{ in.}\#$$

$$A = \frac{50500 \times 8}{15000 \times 24 \times 7} = .16\ \square''/\text{ft.}$$

FREEMAN AND SNOW

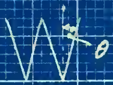


TOP-BEAMS OF PIERS.

DIAGRAM OF STIRRUP SPACING

$f_s = 12000 \,\#/\square''$

Use ½"□ stirrups



Allowable stress

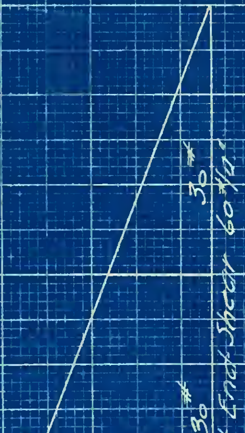
$= A \cdot f_s \sec\theta$

$= 4 \cdot .25 \cdot 12000 \cdot 1.06$

$= 12700\#$

$P = v \cdot b \cdot s$

$P = 22 \cdot 24 \cdot 9 = 4700\#$ O.K.



Use spacing shown for all piers.

Plate VIII

ABUTMENT DESIGN.

a. For Overturning:

Assume the section shown on plate VIII-a, with the various forces acting on it as shown. Find the resulant vertical and horizontal forces and their lever arms by taking moments about the lower right-hand corner of the base.

For Vertical Forces:

FORCE	AMOUNT	ARM	MOMENT
Slab Reaction	13100	10.1	132200
Abutment weight	23600	7.54	178000
Vertical earth pressure	12600	4.1	51800
Earth on rear offset.	4050	0.75	3000
Resultant Vert. Force	53350	6.85	365000#
For Horizontal Forces:			
Horiz. earth pressure	9200	9.3	85600
Earth on rear offset	2250	1.25	2810
Result. Horiz. Force	11450	7.72	88,410

Point of application of final resultant

$= 6.85 + (11450/53350) \cdot 7.72 = 8.50'$

$\therefore e = 8.50 - 7.75 = .75'$ $V = 53350^{\#}$

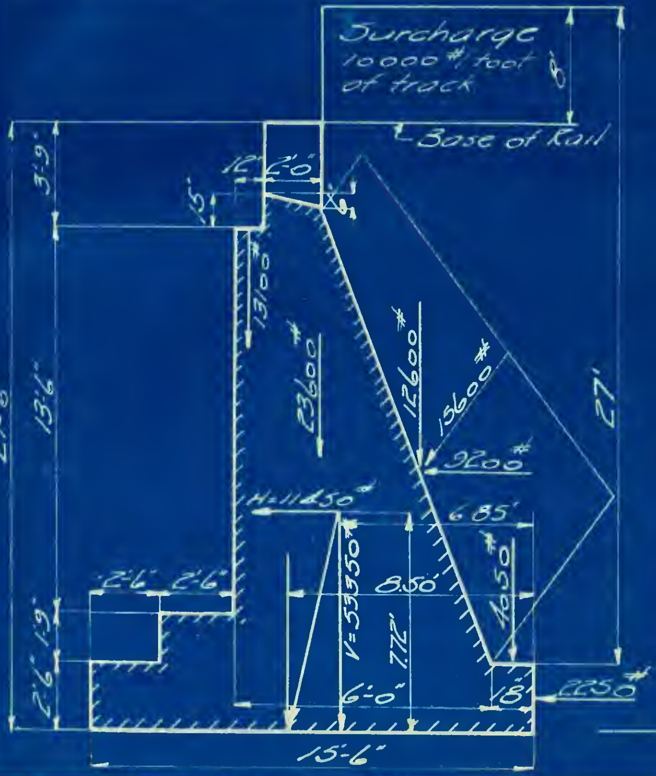
$s_1 = \frac{V}{A}\left(1 + \frac{e}{d}\right)$ $s_2 = \frac{V}{A}\left(1 - \frac{e}{d}\right)$

$$S_1 = \frac{53350}{15.5}\left(1 + \frac{.75}{15.5}\right) = 3610^{\#}/\square'$$

$$S_2 = \frac{53350}{15.5}\left(1 - \frac{.75}{15.5}\right) = 3280^{\#}/\square'$$

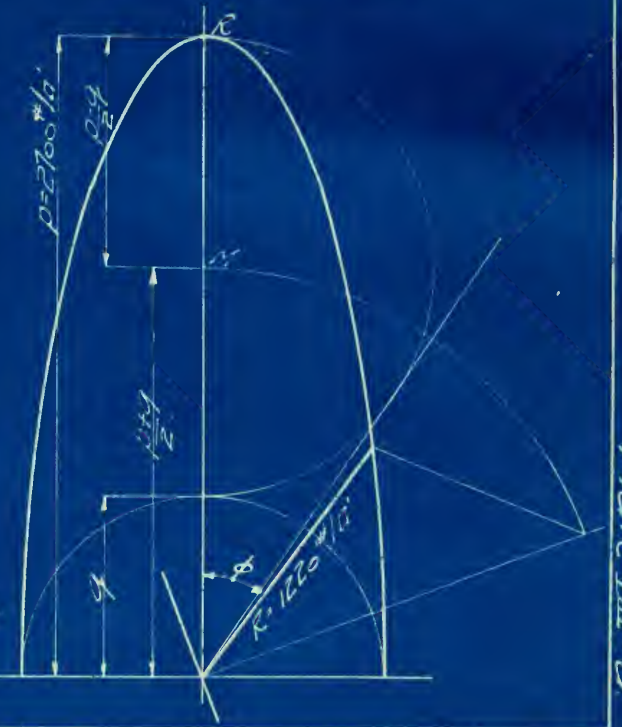
Plate VIII-a

ABUTMENT FORCES.



ELLIPSE OF STRESS.

for a depth of 27'.



Thesis—F.C.D.

b. Investigation for sliding.

Sliding will occur when the inclination of the resultant is greater than the angle of repose of the material.

$\therefore$ angle of inclination = $\tan^{-1} 11450/53350$ = 12°+. As this is less than ϕ (= 33°) the abutment is safe in sliding.

c. Design of cantilever footing.

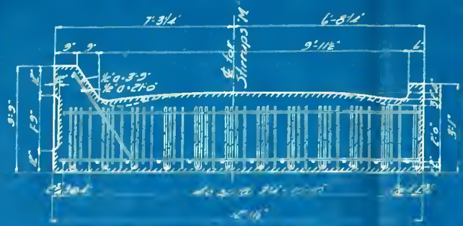
The greatest moment occurs at the front face of the wall and its amount is as follows:

$M = 3610 \times 5 \times 12 \times 1/2 = 108000$ in#

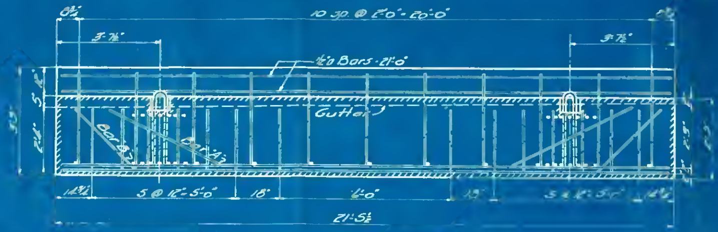
$\therefore A_s = \dfrac{108000 \times 8}{13500 \times 45 \times 7} = .20\ \square''/\text{ft}$

The unit shear at this point

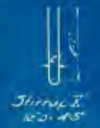
$= v' = 3500 \times 5 / 45 \times 12 = 32\#/\square''$

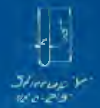


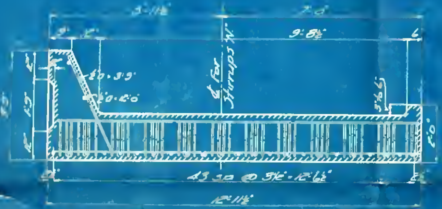
Cross Section of Slab "A"



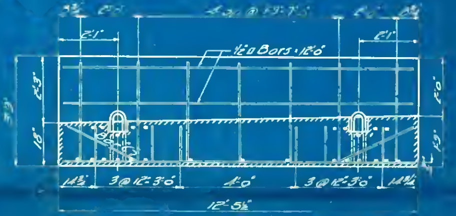
Sectional Elevation on ℄ - Slab "A"


Stirrup "X"
½"ø-4'-5"

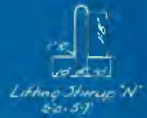

Stirrup "Y"
½"ø-2'-9"

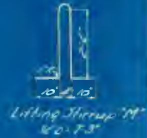


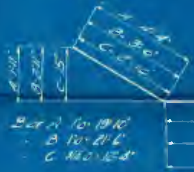
Cross Section of Slab "B"



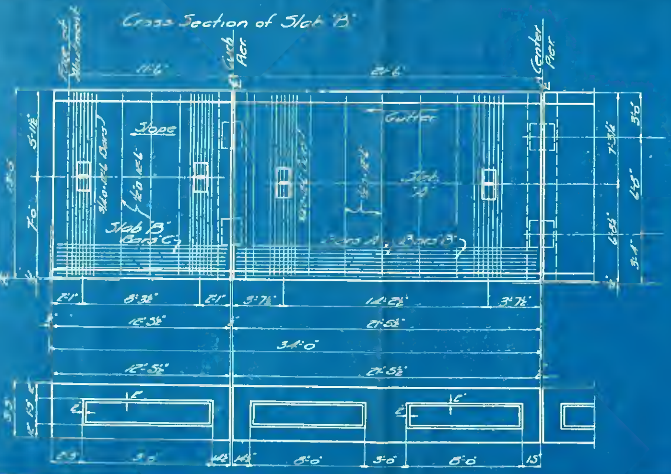
Sectional Elevation on ℄ - Slab "B"

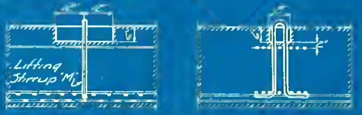

Lifting Stirrup "N"
⅝"ø-5'-7"


Lifting Stirrup "M"
⅝"ø-7'-3"

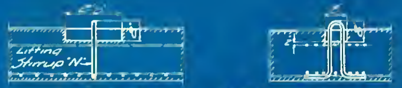

Bar A 1"ø-19'-10"
" B 1"ø-21'-6"
" C ¾"ø-12'-4"

Bar A	15'-6"
" B	18'-6"
" C	9'-6"





Detail Location of Stirrup "M"



Detail Location of Stirrup "N"

Bill of Bars

4 Large Slabs - Mark A				
No.	Size	Leng.	Mk.	Location.
92	1"ø	19'-10"	A	Longitudinal in bottom.
92	1"	21'-6"	B	" " "
672	½"	4'-5"	X	Stirrups.
8	⅝"ø	7'-3"	M	Lifting Stirrups.
148	½"ø	12'-6"		Transverse.
88	½"	3'-9"		Upright in parapet.
16	½"	21'-0"		Longitudinal " "

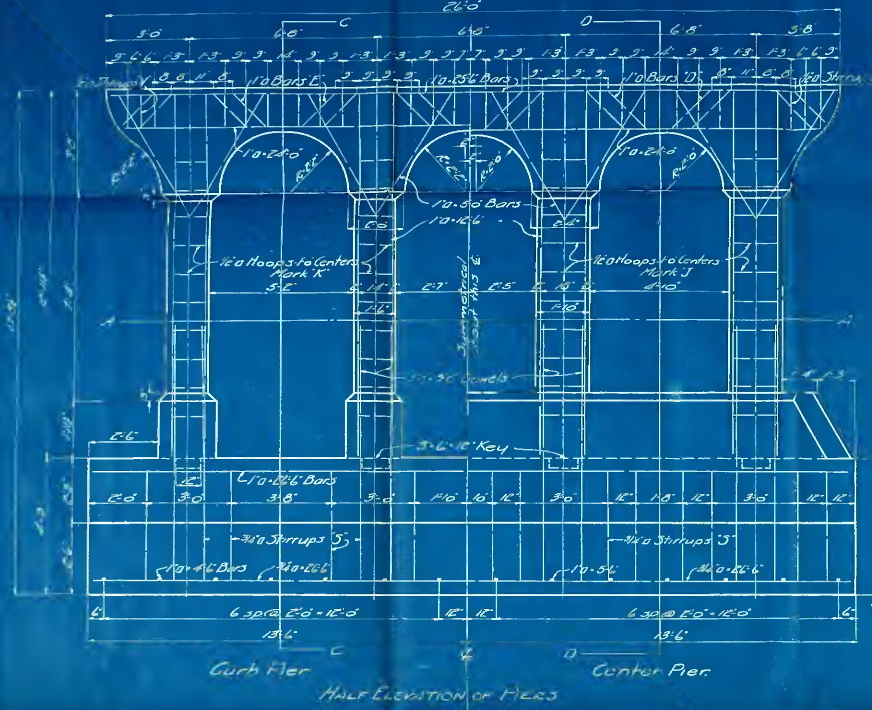
4 Small Slabs - Mark B.				
No	Size	Leng.	Mk.	Location.
180	¾"ø	12'-4"	C	Longitudinal in bottom
364	½"	2'-9"	Y	Stirrups on C bars
8	⅝"	5'-7"	N	Lifting-Stirrups.
88	½"ø	12'-6"		Transverse.
56	½"	3'-9"		Upright in parapet.
16	½"	12'-0"		Longitudinal " "

Thesis Plate II

DETAILS OF SLABS

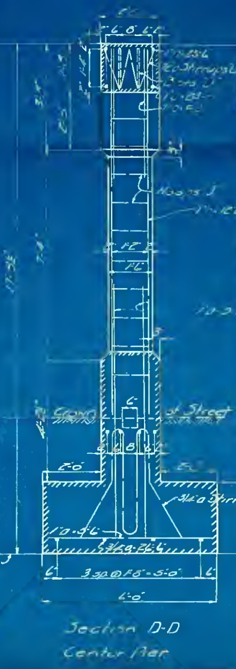
May 5 1912 Scale: ½"=1'-0"

Fred C Dierking

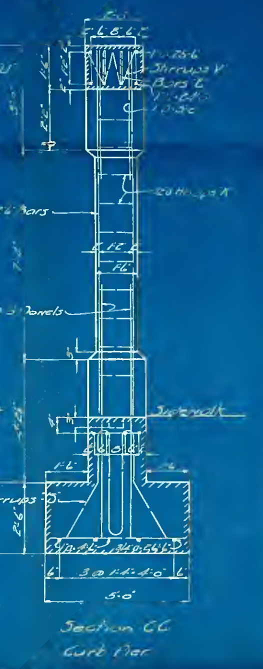


Curb Pier Center Pier

HALF ELEVATION OF PIERS



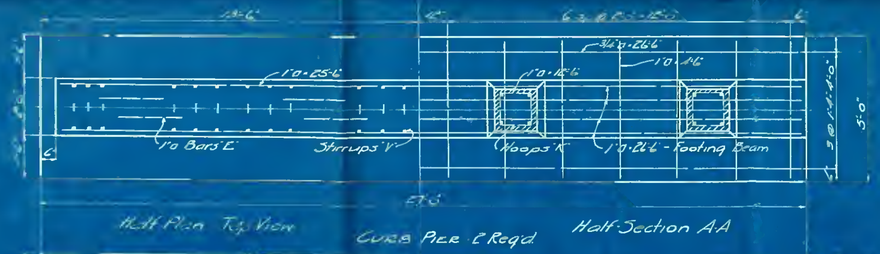
Section D-D
Center Pier



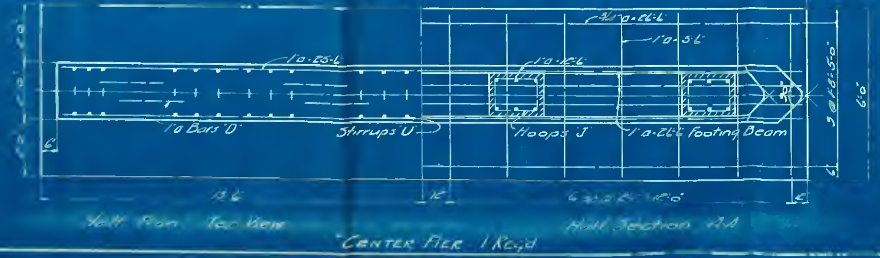
Section CC
Curb Pier

BILL OF BARS

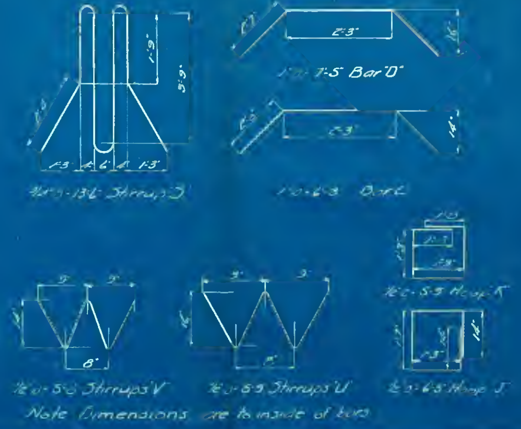
	No.	Size	Leng.	Mk.	Location.
One center Pier	4	¾"	26'-6"		Longitudinal in footing
	4	1"	26'-6"		〃 〃 beam.
	4	1"	24'-0"		Bottom of Top Beam.
	2	1"	25'-6"		Top 〃 〃
	24	1"	12'-6"		Columns.
	24	1"	9'-0"		Dowels
	14	1"	5'-6"		Transverse in Footing.
	8	1"	7'-5"	D	Top Beam - Over columns.
	24	½"	5'-9"	U	Stirrups - Top Beam.
	16	¾"	13'-6"	J	〃 Footing 〃
	16	1"	5'-0"		Diagonals.
	40	½"	6'-5"	J	Hoops.
Two curb Piers	8	¾"	26'-6"		Longitudinal in footing
	8	1"	26'-6"		〃 〃 Beam.
	8	1"	24'-0"		Bottom of Top Beam.
	4	1"	25'-6"		Top 〃 〃
	32	1"	12'-6"		Columns
	32	1"	9'-0"		Dowels
	28	1"	4'-6"		Transverse in footing.
	16	1"	6'-3"	E	Top Beam - over Columns
	48	½"	5'-0"	V	Stirrups - Top Beam.
	32	¾"	13'-6"	J	〃 footing 〃
	32	1"	5'-0"		Diagonals.
	80	½"	5'-3"	K.	Hoops.



Half Plan Top View CURB PIER 2 Req'd Half Section A-A



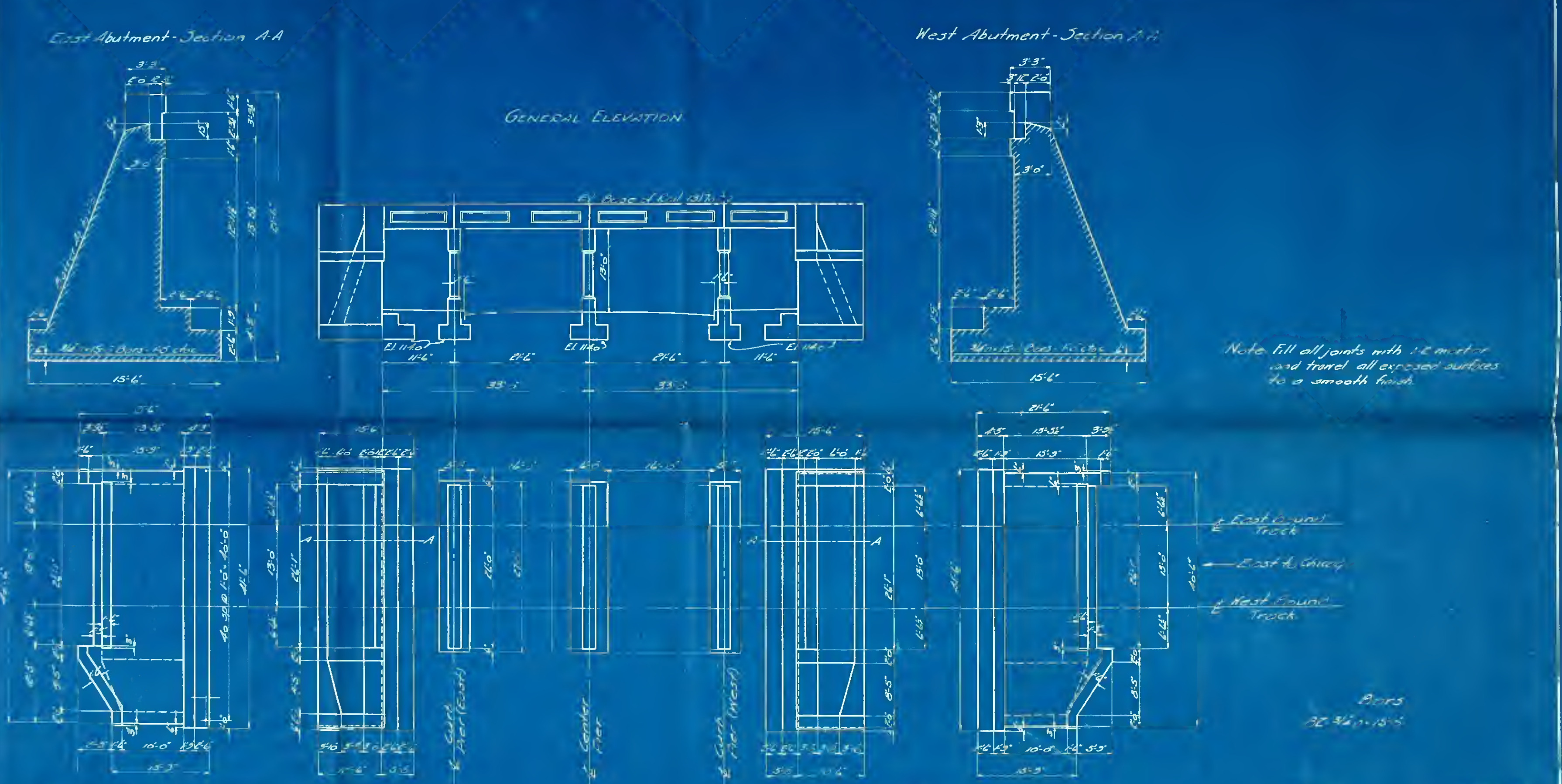
Half Plan Top View CENTER PIER 1 Req'd Half Section A-A



¾"Ø-13'-6" Stirrup J
1"Ø-7'-5" Bar D
1"Ø-6'-3" Bar E
½"Ø-5'-0" Stirrups V
½"Ø-5'-9" Stirrups U
½"Ø-5'-3" Hoop K
½"Ø-6'-5" Hoop J
Note Dimensions are to inside of bars

Construction Notes:
All corners to be beveled
Footing mixture 1:2½:5
Neatwork 〃 1:2:4

Thesis Plate I
DETAILS OF PIERS
May 5 1912 Scale ½"=1'-0"
Fred C [illegible]enting



Note. Fill all joints with 1:2 mortar
and trowel all exposed surfaces
to a smooth finish.

Thesis — Plate XI

ABUTMENTS AND GENERAL LAYOUT

May 5, 1912 — Scale 1/8"=1'0"

Fred C. Dierking